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## REFLECTIVITY OF SEA SURFACE FOR DOPPLER RADAR

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NRL REPORT R-3418

# REFLECTIVITY OF SEA SURFACE FOR DOPPLER RADAR

E. F. McClain and W. R. Ferris

February 16, 1949

Approved by:

Mr. J. P. Hagen, Head, RF Research Section  
Dr. J. M. Miller, Superintendent, Radio Division I



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**CONTENTS**

Abstract	vi
Problem Status	vi
Authorization	vi
INTRODUCTION	1
PROCEDURE	1
CONCLUSIONS	5
REFERENCES	7

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#### ABSTRACT

Measurements were made of the reflectivity of the sea surface using a Doppler-type radar. It was found that the reflected energy decreased rapidly when the transmission angle from the vertical exceeded 15 degrees. In one case the loss at 20 degrees was 65 db greater than the theoretical loss for a perfect plane reflector at normal incidence. Measurements of the Doppler frequency returned by the moving water surface indicate that high accuracies are improbable in a Doppler ground speed indicator used at low speed.

#### PROBLEM STATUS

This is an interim report on this problem; work is continuing.

#### AUTHORIZATION

NRL Problem R04-12D (Bureau of Aeronautics Project TED NRL AE-9110).

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## REFLECTIVITY OF SEA SURFACE FOR DOPPLER RADAR

### INTRODUCTION

One of the limiting factors in the design of a Doppler ground speed indicator is the reflectivity of the sea surface. From the standpoint of accuracy it would be desirable to point the antenna as near the horizon as possible. However, the strength of the received signal falls off rapidly as the angle of the antenna is changed from 0 degrees, or vertical, to 90 degrees, or horizontal. For a given system and altitude there is then a maximum angle from the vertical at which the antenna may be pointed beyond which it fails to maintain a usable signal-to-noise ratio.

### PROCEDURE

Previous measurements of sea reflectivity made by the Naval Research Laboratory<sup>1</sup> were somewhat limited with respect to the sea states available. It was decided, therefore, to make additional measurements in a more favorable location. The site chosen was the Golden Gate Bridge, which has a considerable height and an unobstructed view of the open sea.

The equipment used was similar to that previously described<sup>2</sup>: a two-antenna, zero-frequency, c-w Doppler system. Unfortunately no magnetrons were available at the time of the measurements so that a 723A/B klystron was used as a transmitter. It had been hoped that extensive measurements of Doppler frequency due to wave motion versus transmission angle could be made. However, due to the low transmitter power, the system signal-to-noise ratio at large angles was too low to permit accurate frequency measurements. The system had a power output of 17 mw at 3.2 cm, and 30-inch parabolic antennas were used. The frequency response of the audio circuits was linear down to 20 cycles per second, which corresponds to a radial velocity of approximately 0.62 knot. All frequency measurements indicated velocities of at least 1.2 knots, so that no appreciable errors were introduced by the frequency response of the system. The equipment was calibrated so that it was possible to determine the actual power intercepted by the receiving antenna. Knowing the transmitted power, it was possible to refer the reflectivity of the sea to some convenient standard such as a perfect plane reflector. The antennas were mounted on a small platform which projected over the side of the bridge. This permitted an unobstructed view of the sea surface when the antennas were pointed vertically down. The height of the antennas was 234 feet above the water surface.

<sup>1</sup> NRL letter report C-390-305/45 dated 9 Aug. 1945.

<sup>2</sup> NRL letter report C-1390-106/47 dated 14 July 1947.

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If the above system were located above a perfect plane reflector and pointed vertically down, there would be a loss in received power due to the finite beam width of the transmitting antenna and the finite capture area of the receiving antenna. This loss may be calculated as follows:

$$\text{Ratio of } \frac{\text{transmitted power}}{\text{received power}} = \frac{64R^2}{nGD^2},$$

where: R = range or distance to reflector,

n = illumination factor of receiving antenna  
(taken to be 0.65),

G = gain of transmitting antenna over an  
isotropic radiator, and

D = diameter of receiving antenna in same  
units as R.

For the conditions in this test, the above loss was 24 db.

This, then, should have been the path loss looking normally at the water surface if the surface were a perfect specular reflector. Since the equipment had been previously calibrated, it was possible to interpret a reading of received power as an actual path loss, and in turn to consider a given sea state and transmission angle as having a certain loss relative to a perfect plane surface at normal incidence in the horizontal plane.

Figures 1 and 2 show the results obtained. In Figure 1 all the data obtained were averaged at each transmission angle and the result plotted as the average curve. In addition, the highest and lowest losses at each angle were plotted. These latter two curves show the highest signal return which could be expected and the lowest return which was encountered in these tests. Obviously, the highest loss figures must be used in design of equipment which is to have extreme reliability.

Figure 2 is a plot of the results obtained during the course of one day, during which time the sea changed from smooth rollers to quite rough waves with white caps.

Figure 3 is a plot of the Doppler frequency returned and radial velocity versus the transmission angle  $\theta$ . The signal-to-noise ratio beyond 30 degrees was not great enough to ensure an accurate measurement of frequency. However, it is evident that when using a Doppler ground speed indicator there will be a residual velocity present due to wave motion. This apparent velocity is due to two different velocity components in the sea surface. One is a vertical reciprocating motion, which dominates if the transmission angle is small. This will cause a frequency modulation of the Doppler frequency obtained in a moving aircraft. The character of this modulation will change with altitude, i.e., area of reflecting surface, but any errors will be small. The other component is a horizontal motion of the reflecting surface, which dominates at large transmission angles and which will cause errors at any aircraft speed. The horizontal velocity is found by dividing the radial velocity by  $\sin \theta$ . This is accurate only above about 20 degrees, since the vertical motion masks the horizontal motion at small angles when the equipment is stationary. The horizontal velocity in this example is 2 knots when corrected for tidal currents. This velocity gives rise to a percentage error, which will decrease as the aircraft speed increases.

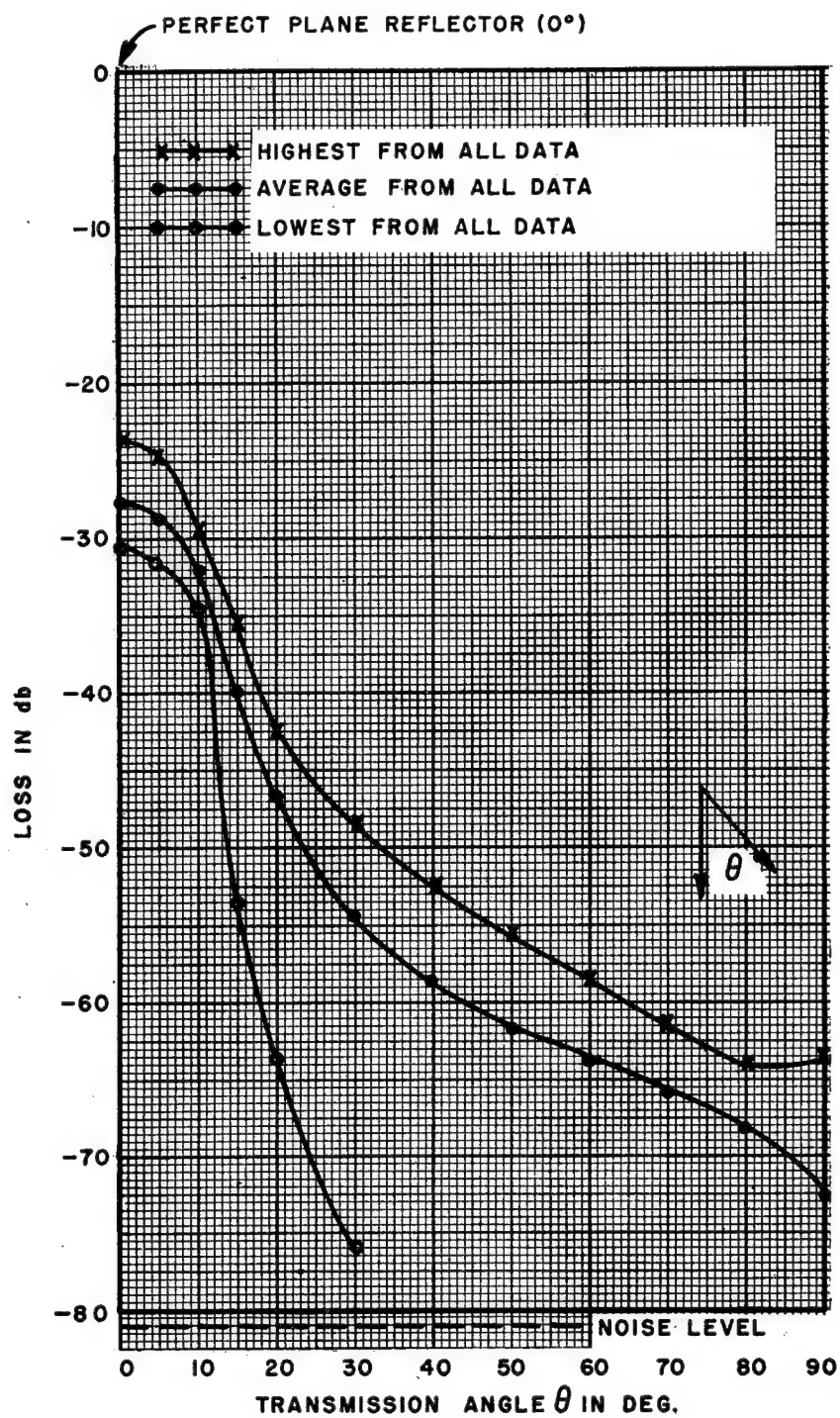


Fig. 1 - Loss Relative to a Perfect Plane  
at Zero Degrees

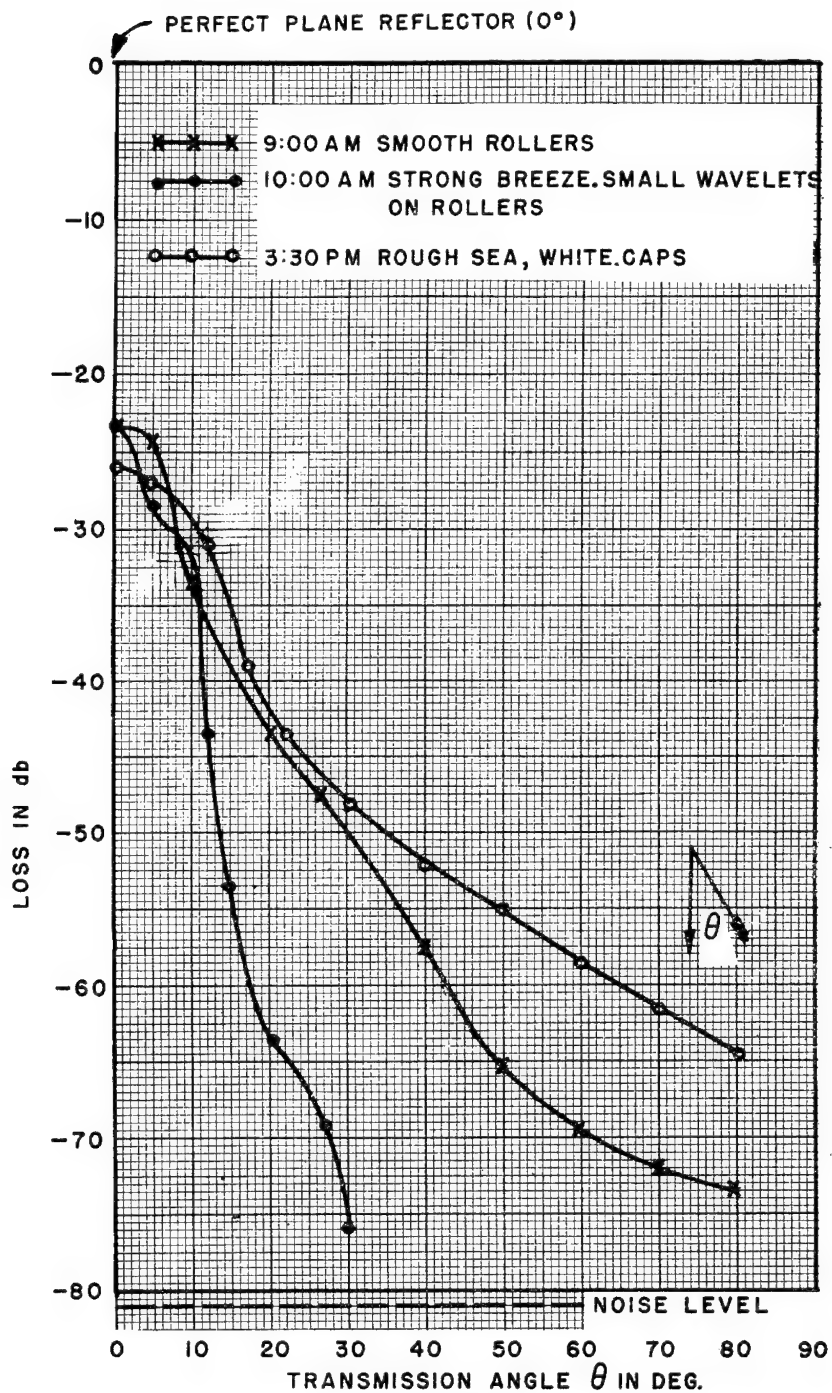


Fig. 2 - Representative Runs Taken Aug. 19, 1948  
From West Side of Golden Gate Bridge

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To: Holders of NRL Report R-3418 "Reflectivity of Sea Surface  
for Doppler Radar" (Confidential)

Subj: NRL Report R-3418 - Correction of Figure 2.

1. The key to Figure 2, p. 4 of subject report is in error.
2. The key should read as follows:

●—●—● 9:00 AM SMOOTH ROLLERS

×—×—× 10:00 AM STRONG BREEZE, SMALL WAVELETS  
ON ROLLERS

○—○—○ 3:30 PM ROUGH SEA, WHITE CAPS

3. It is requested that this correction be inserted in each  
copy of subject report.

*B. T. Morris*

B. T. Morris  
By direction

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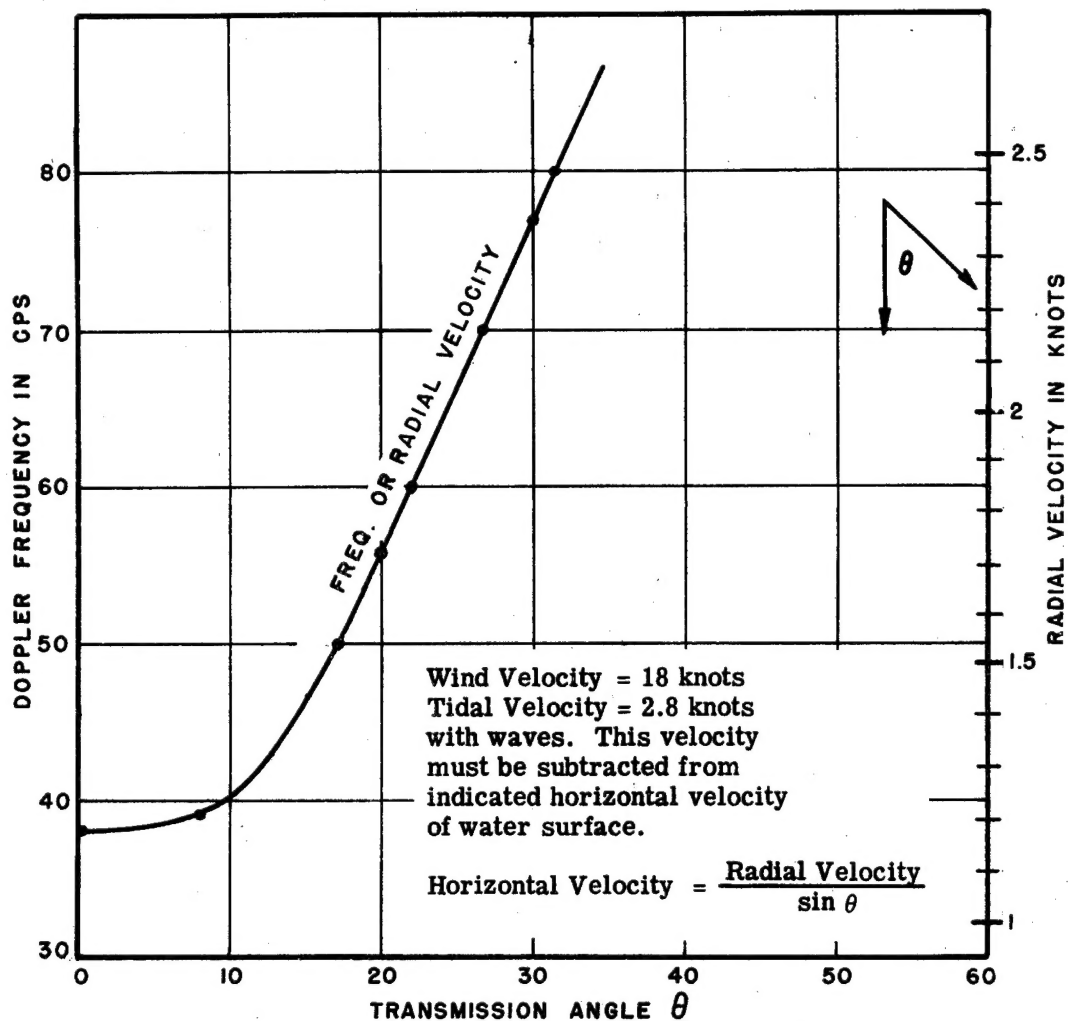


Fig. 3 - Doppler Frequency and Radial Velocity vs Transmission Angle  $\theta$

All the above measurements were made broadside to the wavefronts, which attitude gives maximum return and, in addition, gives the maximum indicated velocity due to wave motion. All measurements were made with vertical polarization, which had previously been found to give the highest intensity of return. Tide data were taken from "Tide and Current Tables" of the San Francisco Bar Pilots. Wind data were taken from a recording anemometer installed on the bridge.

#### CONCLUSIONS

It is seen from Figures 1 and 2 that antenna angles in excess of 15 degrees or 20 degrees will entail extremely high losses on occasion, and in turn will limit the altitude

to which a given system will work. The present NRL system<sup>3</sup> will operate to 55,000 feet under the worst conditions found, when using a transmission angle of 15 degrees. The calculated signal-to-noise ratio will be 20 db under these conditions.

From Figure 3 it is seen that any Doppler system operating over water in slow moving craft will be impractical if high accuracy is desired. In the example shown, the indicated horizontal velocity of the water is approximately 2 knots when the wind velocity is 18 knots. For this example the error velocity is 11 percent of the wind speed. A plane flying broadside to the waves over this particular water would have had to maintain a speed of 200 knots to maintain an accuracy better than 1 percent in indicated ground speed. A detailed study of the effects of water waves on accuracy would require a statistical analysis of a great mass of data taken from all water over which one expected to fly. However, it appears probable that accuracies better than 1 percent will not be attained more than 50 percent of the time unless the aircraft is flying in excess of 200 knots. It should be understood that these errors are not a function of the type of Doppler system used, but rather a function of the nature of the sea. It appears that for average sea conditions a speed of over 200 knots is required to obtain an accuracy of 1 percent.

The detailed implications of the results of these tests as they pertain to a Doppler ground speed indicator will be taken up in a forthcoming report which will deal with all the parameters of such a Doppler system.

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<sup>3</sup> NRL letter report C-1390-106/47 dated 14 July 1947.

\* \* \*

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#### REFERENCES

- (a) BuAer ltr Aer-E-339-IDS F31-1(12) NP14 of 21 August 1943 to Dir. of NRL (SRPPB)
- (b) Estes, C. L. and Gibson, J. E., "Flight tests of a ground speed indicator," NRL Report R-2552, 5 June 1945 (Confidential)
- (c) Estes, C. L. and McClain, E. F., "Flight tests of a ground speed indicator over measured runs," NRL Report R-3239, 11 February 1948 (Confidential)
- (d) Hulburt, E. O., "Report on the Doppler frequency change in radiation reflected from the waves of the sea," NRL Report H-2422, 19 December 1944 (Unclassified)
- (e) McClain, E. F. and Giles, R. C., "An f-m test set for microwave oscillators," NRL Report R-3361, 27 September 1948 (Confidential)
- (f) NRL ltr report C-1390-211/47 (1391/wd) to BuAer dated 2 January 1948

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